7. Quantifying soil chemical degradation associated with changed land use and the development of an acidity risk map for Northeast Thailand

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Abstract
The conversion of climax *Dipterocarp* forest for agricultural purposes has resulted in a decline in productivity of light textured soils in Northeast Thailand. In order to quantify the degree of chemical degradation that these soils have undergone, a survey was undertaken of 6 representative paired sites where adjacent *Dipterocarp* forest soils were compared to continuously cropped systems that had been under production from 37 – 100 years. Surface charge fingerprints along with soil chemical and physical attributes were determined on selective depth intervals. Significant declines in exchangeable cations and soil organic carbon were observed under the cropped systems resulting in dramatic declines in the surface charge characteristics. The amount of soil organic carbon lost in the 0-10 cm depth interval under the cropped system ranged from 3.84 to 10.11 t/ha. Using a saturation index (S_u) that encompasses an assessment of the degree of degradation taking into account the previous land use, in this case *Dipterocarp* forest, and that due to anthropogenic disturbance was used to quantify charge diminution. S_u values ranged from 52.9 – 90.3 % clearly indicating the degree of degradation these systems have undergone due to changed management. Mean net acid addition rates (NAAR) were calculated for cassava and rice production systems that dominate the upland and lowland areas of Northeast Thailand. Values ranged from 1.05 – 1.50 kmol H^+/ha.yr for the cassava and rice systems respectively. A highly significant pedotransfer function was established to estimate pH buffering capacity (pHBC) using the routinely determined soil attributes of soil organic carbon and clay content. Using this pedotransfer function and the NAAR rates of each of the cropping systems, acidity risk maps were produced for Northeast Thailand for each of the crop production systems.

Introduction
Light textured sandy soils are common throughout the tropics and constitute an important economic resource for agriculture despite their inherent infertility (Panichapong, 1988). Such soils occupy a significant area of the Northeast Thailand plateau (Ragland and Boonpuckdee, 1987), and though originally dominated by climax *Dipterocarp* forests until 40 years ago, were then extensively cleared for timber and agriculture. Continuous production of crops such as rice, kenaf (rosella), cassava, and sugarcane has resulted in a rapid decline in the fertility status of these soils, with an associated loss of productivity. Northeast Thailand is considered to be a region of limited resources. The major limiting factors are the low inherent fertility of soils, scarcity of water resources, and erratic rainfall patterns and distribution (Panichapong, 1988). Rice is frequently grown in this region on land that has an undulating topography. Initially farmers establish rice crops in this type of topography at the bottom of depressions and subsequently progress up the slope towards the upland (Limpinuntana, 1988). Rice production in the bottom or lower paddies is considerably more stable than rice grown in the upper paddy fields. In this respect rice can only be grown in the upper paddy fields for one to three years out of five because of insufficient water for transplanting (Limpinuntana, 1988). These upland soils have been extensively leached and eroded and consequently have a low inherent fertility, low cation exchange capacity, sandy texture, low water holding capacity, low organic matter content and are acid. Consequently, farmers have moved towards low-input and long–duration crops such cassava and kenaf.

The impact of changed land use on charge characteristics is eloquently encapsulated in the charge fingerprint as described by Gillman and Sumpter (1986). This technique provides an assessment of the negative charge characteristics of a soil over the range of pH values that have agronomic significance. It is therefore able to distinguish that portion of the CEC that has the ability to retain basic cations, and predicts changes in CEC as soil solution pH and ionic strength are varied. In addition, it allows an estimation to be made of permanent and variable charge, the influence of components such as organic matter on surface charge expression, and the effects on surface charge associated with anthropogenic disturbance.

In the current study, undertaken in collaboration with CSIRO and Queensland Department of Natural Resources and Mines through funding from Australian Centre for International Agricultural Research (ACIAR), the focus is on the quantification of changes in surface charge characteristics associated with changed land management under two contrasting cropping systems, namely rice and cassava. When used in conjunction with exchangeable cations extracted from the exchange complex, an assessment of the current and potential cation holding capacity and the impact of imposed management systems can be objectively assessed. Through the construction of charge fingerprints a Saturation Index (S_u) (Noble *et al*., 2000) was calculated with respect to base cation content and an estimation of the degree of degradation that the soils had undergone from a 'benchmark' state, in this case, remnant *Dipterocarp* forest. Quantification of the Net Acid Addition Rate (NAAR) under different crop production systems was undertaken. A pedotransfer function to predict soil pH buffering capacity (pHBC) was developed based on intrinsic characteristics of the soil, namely soil organic carbon and clay content, for the suite of soils sampled. Using the pHBC pedotransfer function and the NAAR, acidity risk maps based on a current GIS linked soil data sets for the region were developed for the different cropping systems.

Materials and methods

Site

A total of 6 paired sites were selected that traversed a toposequence from uplands to lowlands in Northeast Thailand (Table 1). The selection of sites was based on the following criteria: (1) the existence of an undisturbed Dipterocarp forest in close proximity to an agricultural production system; (2) a well defined boundary separating the two production areas; (3) the same soil type in both areas; and (4) little topographical difference (i.e. slope) between the two areas. Samples were collected at five points in each area along a transect at right angles to the boundary separating the two systems. Sampling points were 5 m apart and at each point three augur holes (10 cm diameter) were made and soil samples collected from the 0-10, 10-20, 20-30, 30-50 and 50-70 cm and bulked to form a composite sample.

Soil analysis

Samples were air dried and sieved to pass a 2 mm mesh. In this initial phase of analysis, a bulked composite sample was made for each of the paired sites of the following depth intervals: 0-10, 20-30 and 50-70 cm. Basic exchangeable cations were determined by atomic absorption spectrometry after replacement with 0.1 M $BaCl_2$-NH_4Cl as recommended by Gillman and Sumpter (1986). Acidic cations were extracted with 1 M KCl and the extractant titrated to pH 8.0 as described by Rayment and Higginson (1992). The effective cation exchange capacity (ECEC) was calculated as the sum of basic and acidic cations (Ca^{2+}+Mg^{2+}+K^++Na^++Al^{3+}+H^+). Soil organic carbon was determined by wet oxidation using the Walkley and Black method as modified by Rayment and Higginson (1992) and particle size as described by Coventry and Fett (1979).

Table 1. Selected information of the six sites collected in Northeast Thailand.

Sample No.	Province	Soil Form	FAO classification	Production system	GPS location	Parent material	Land form	Vegetation	Years under production system.	Comments
A1-5 (C 1)	Sisaket	Korat	Gray Podzolic	Forest	15° 16' 33" N 104° 01' 05"E	Alluvium	High terrace	DDF	Unknown	Community forest for 14 years
A6-10	Sisaket			Cassava	15° 16' 33" N 104° 01' 05"E	Alluvium	High terrace	DDF	40	
B1-5 (C 2)	Sisaket	Yasothon	Red Yellow Latosol	Forest	15° 17' 01" N 104° 01' 22"E	Alluvium	High terrace	DDF	Unknown	Community forest for 14 years
B6-10	Sisaket			Cassava	15° 17' 01" N 104° 01' 22"E	Alluvium	High terrace	DDF	40	
C1-5 (C 3)	Sisaket	Korat	Gray Podzolic	Forest	15° 16' 18" N 104° 01' 44"E	Alluvium	Middle terrace	DDF	Unknown	Community forest for 14 years
C6-10	Sisaket			Cassava	15° 16' 18" N 104° 01' 44"E	Alluvium	Middle terrace	DDF	38	
F1-5 (R 3)	Yasothon	Roi-et	Low Humic Gley	Forest	15° 35' 59" N 104° 10' 38"E	Alluvium	Low terrace	DDF	Unknown	National Reserved forest
F6-10	Yasothon			Low land rice	15° 35' 59" N 104° 10' 38"E	Alluvium	Low terrace	DDF	37	
G1-5 (R 4)	Roi-et	Roi-et	Low Humic Gley	Forest	15° 47' 36" N 103° 57' 04"E	Alluvium	Low terrace	DDF	Unknown	Spiritual forest
G6-10	Roi-et			Low land rice	15° 47' 36" N 103° 57' 04"E	Alluvium	Low terrace	DDF	50	
H1-5 (R 5)	Roi-et	Roi-et	Low Humic Gley	Forest	15° 49' 29" N 103° 55' 51"E	Alluvium	Flood plain	Swamp forest	Unknown	Spiritual forest
H6-10	Roi-et			Low land rice	15° 49' 29" N 103° 55' 51"E	Alluvium	Flood plain	Swamp forest	100	

Charge Fingerprints were determined on the composite samples from each site using the methodology described by Gillman and Sumpter (1986). Records of the amounts of acid or base added to the tubes during the equilibration phase were kept and these converted to $cmol_c$ H^+/OH^- added /kg of soil. These values were plotted against the equilibrium pH for each tube and the inverse of the slope of this relationship was taken to be the pH buffering capacity (pHBC) of the soil.

The regression analysis routine of Genstat (Genstat 5 Committee, 1993) was used to investigate relationships between pHBC and selected soil properties to establish a pedotransfer function that could be used to estimate this parameter. Curves associated with the charge fingerprints were fitted using the curve fitting function of SigmaPlot 4.0 for Windows.

Soil chemical degradation index

A Saturation Index (S_u) as proposed by Noble *et al*., (2000) was used to quantify charge diminution associated with changed land use. The S_u index has the following format:

$$S_u = 100 \text{ x } (C_{u5.5} - \Sigma) / C_{u5.5} \quad (1)$$

where $C_{u5.5}$ refers to the cation exchange capacity at pH 5.5 of the undisturbed (*Dipterocarp* forest) soil as determined from the charge fingerprint, and Σ is the sum of the base cations actually present in the system under review. A low S_u indicates closeness to the ideal condition for that particular soil.

Estimation of net acid addition rate

The net acid addition rate (NAAR, kmol H^+/ha. year) to the agricultural production system was calculated relative to the adjacent undeveloped *Dipterocarp* forest at each site for the 0-15 and 15-30 cm depth interval using the following equation (Helyar and Porter, 1989):

$$\text{NAAR} = [((pH_F \text{ x } pHBC_F) - (pH_C \text{ x } pHBC_C)) \text{ x BD x V}]/T \quad (2)$$

where the subscripts F and C refer to the undeveloped *Dipterocarp* forest and developed agricultural production system respectively; pHBC is the pH buffering capacity for each of the (kmol H^+. kg^{-1}. pH $unit^{-1}$) of the developed and undeveloped areas; BD is soil bulk density which was taken to be 1300 kg m^{-3}; V is the soil volume in the depth interval under consideration (m^3 ha^{-1}); and T is time (years) since the change in land use system. The net acid addition due to the change in land use was estimated from the sum of two depth intervals.

Development of an acidity risk map for Northeast Thailand

The procedure adopted for the development of an acidity risk map was similar to that described by Noble *et al.* (2002). Using the developed pedotransfer function, a pHBC was assigned to each of the soil series that are present in Northeast Thailand. This is based on the current soil resource map at 1:100,000 scale of the Department of Land Development, Khon Kaen, Thailand. A total of 34 soil series make up this resource map. Using a modification of the model proposed by Helyar and Porter (1989) the following equation was used to calculate the time (T) in years for the pH of the surface soil to drop from its current pH to a pH of 5.0.

$$T = [(pH_i - 5.0) \times pHBC \times BD \times V]/NAAR \quad (3)$$

where T is time in years; pH_i is the current measured soil pH; pHBC is mean pH buffering capacity of the soil association (kmol H^+/kg.pH); BD is the mean soil bulk density assumed to be 1300 kg/m^3; V is volume of soil in the 0-20 cm depth interval; and NAAR is net acid addition rate (kmol H^+/ha. year) which was assumed to be 1.05 and 1.50 kmol H^+/ha.year for the cassava and rice systems respectively.

Results and Discussion

Site history

The Northeast of Thailand has undergone dramatic changes in land use over the past 40 years. This has included a move away from subsistence based agriculture to commercial based farming systems. As such lands that have traditionally been used for paddy production have, in some cases, been used specifically for subsistent rice production for more than 100 years. A move towards upland crop production was started approximately 40 years ago with cassava and sugarcane becoming dominant components of these systems in the last 20 years. The production system is characteristically a rotation that consists of a 5 year cropping cycle followed by a 2-3 years fallow as a means of improving the fertility of these light textured soils.

Soil chemical and physical properties

The soil series represented at the 6 sites were the Roi-et (fine-loamy, mixed, isohyperthermic Aeric Paleaquults); Korat (fine-loamy, siliceous, isohyperthermic Oxic Paleustults); and Yasothon (fine-loamy, siliceous, isohyperthermic Oxic Paleustults) (Soil Survey Staff, 1990) (Table 1). All of these series were formed from old alluvium and occur on low, middle and high terraces respectively. These soils are dominated by coarse and fine sand with very low clay contents (range: 2.4 – 15.5%) (Table 2 and 3). The texture is relatively uniform down to depth within the profile.

Soil pH, organic C, exchangeable basic and acidic cations, effective cation exchange capacity (ECEC), pHBC, CEC_b and CEC_t for each of the depth intervals are presented in Table 2 and 3. Differences in pH between the *Dipterocarp* forest and adjacent cultivated sites were not markedly different and no clear trends were observed with respect to changes in pH (Table 2 and 3). In three cases (C1, C2, R5) there was a small decline in the pH of the surface 0-10 cm between the forest and cultivated sites. Differences in exchangeable acidity reflected trends in soil pH with an increase in exchangeable acidity with a decline in pH. Exchangeable acidity was in several cases the dominant cation on the exchange complex as soil pH declined. Exchangeable basic cations were lower in the 0-10 cm depth interval on the disturbed sites, however this trend was reversed with depth suggesting that leaching of basic cations from the surface layer to depth had occurred as a resulted of changed land use (Tables 2 and 3). Of the exchangeable bases, Ca^{2+} dominated the exchange complex. It is of note that the concentration of K^+ on the exchange complex was very low in the surface 0-10 cm of cultivated sites, suggesting these soils would respond to prophylactic applications of K based fertilizers and that there had been significant removal or loss of K with changed land use.

Over the intervening period since conversion from forest to continuous agriculture, soil organic carbon declined markedly in the upper soil layers (0-10 cm) (Table 2 and 3). The loss in soil organic carbon resulting from cultivation ranged from 3.84 t/ha on site R3 through to 10.11 t/ha on site R5, a site previously dominated by swamp forest (Table 4). Clearly such dramatic declines in C would have a significant impact on properties associated with cation retention, pH buffering and water holding capacity of these soils.

Surface charge fingerprints

The dominant soil series of Northeast Thailand are sandy with little organic C, and have a clay mineralogy dominated by highly ordered kaolinite and oxides (Panichapong, 1988). Therefore these soils have only modest surface charge, with both permanent and variable charge components. For brevity graphical representations of surface charge fingerprints for each of the composite depths for the forest and cultivated sites are presented for two of the six sites (Figures 1 and 2). The general trend exhibited for each site is that the greatest degree of charge diminution occurred in the surface 0-10 cm depth interval. A distinctive characteristic of the curves derived for the 0-10 cm depth interval at the C1 site is that the negative charge generated varied from approximately 1.1 to 2.1 $cmol_c\ kg^{-1}$ and 0.5 to 1.2 $cmol_c\ kg^{-1}$ over the pH range for the forested and cultivated sites respectively (Figure 1). Conversely, for the same depth interval, the negative charge generated for the R4 site ranged from 0.8 to 1.8 $cmol_c\ kg^{-1}$ and 0.2 to 0.8 $cmol_c\ kg^{-1}$ over the imposed pH range (Figure 2). The greatest difference in the shapes of the charge curves was observed in the surface horizons, this being ascribed to the larger organic carbon content (Table 2) under the forest sites and clearly quantifies the potentially deleterious impact of clearing and subsequent for agriculture on soils with a relatively low permanent charge component. In short, the role of organic C in maintaining negative charge on these soils is critical for the retention and supply of cations. The fact that the greatest degree of degradation occurs in the surface layers is somewhat heartening since remediation of this charge decline is possible through either soil organic matter conservation or other engineering solutions.

For comparisons of surface charge diminution with depth due to changed land use, the CEC_b at pH 5.5 was calculated from the surface charge regression curves for each of the sites and are presented in Table 2 and 3. In general the greatest differences between CEC_b at pH 5.5 were observed in the surface 0-10 cm (Table 2 and 3). These differences diminished with depth in all cases other than at sites C3 and R5 where the CEC_B increased under the cultivated system. This can in part be attributed to the increase in clay content at depth under the cultivated system indicating a degree of heterogeneity of soils at certain site. The decline in organic carbon with cultivation invariably alters the ratio of organic-to-inorganic surfaces, resulting in marked changes in the surface charge characteristics of the soil. In this respect organic carbon has a direct influence on the CEC of the soil as has been clearly demonstrated by Willett, (1995) for light textured sandy soils of Northeast Thailand. Consequently, conservation of organic matter should therefore become the focus of land management strategies.

The charge fingerprint allows an estimate CEC_T at the inherent soil's pH. If the basic and acidic cations removed by the $BaCl_2$-NH_4Cl and KCl extractants respectively are all exchangeable cations then their sum (the ECEC) should be equal to CEC_T at soil pH, within the limits of the experimental error. A graph of ECEC against CEC_T at the soil's pH for the forested and cultivated soils shows excellent agreement between these independently determined properties for all depth intervals suggesting that most of the cations extracted were effectively on the exchange complex (Figure 3). Points showing the greatest deviation from the 1:1 line were from surface horizons suggesting some of the cations extracted were not associated with the exchange complex.

Table 2. Selected chemical and physical properties of composite samples collected from selected depth intervals from paired sites in Northeast Thailand that are currently under a Cassava cropping system.

Site No.	**Depth**	**Vegetation**	**$pH_{0.002}$**	**OC**	**Ca^{2+}**	**Mg^{2+}**	**K^{+}**	**Na^{+}**	**Exch. acidity**	**ECEC**	**$CEC_{B5.5}$**	**CEC_T**	**pHBC**	**C sand**	**F Sand**	**Silt**	**Clay**
	(cm)			(%)	(cmol$_c$/kg)								(cmol$_c$/ kg.pH)	(%)			
C1	0-10	Forest	5.18	0.667	0.742	0.404	0.092	0.003	0.115	1.356	1.571	1.402	0.922	47.2	43.0	5.0	4.9
C1	20-30	Forest	4.95	0.399	0.184	0.231	0.041	0.004	0.628	1.087	1.132	1.043	0.665	45.9	42.4	4.3	7.4
C1	50-70	Forest	5.18	0.114	0.039	0.173	0.015	0.002	0.495	0.725	0.602	0.640	0.249	44.9	44.9	4.7	5.5
C1	0-10	Cassava	5.00	0.327	0.250	0.109	0.034	0.001	0.354	0.749	0.827	0.608	0.625	46.5	45.7	3.0	4.7
C1	20-30	Cassava	4.86	0.364	0.169	0.067	0.027	0.001	0.978	1.242	1.162	1.084	0.599	40.7	46.8	4.5	8.0
C1	50-70	Cassava	5.04	0.103	0.152	0.049	0.013	0.003	0.617	0.834	0.742	0.750	0.284	40.8	47.8	4.8	6.6
C2	0-10	Forest	5.05	1.081	0.798	0.454	0.068	0.003	0.219	1.541	2.091	1.767	1.142	39.5	46.4	6.4	7.7
C2	20-30	Forest	4.96	0.570	0.215	0.256	0.051	0.003	0.616	1.141	1.292	1.137	0.762	35.3	49.1	5.2	10.3
C2	50-70	Forest	4.91	0.210	0.093	0.119	0.015	0.004	0.684	0.915	0.969	0.858	0.508	37.8	45.4	5.2	11.6
C2	0-10	Cassava	5.02	0.427	0.338	0.113	0.036	0.003	0.435	0.924	0.912	0.768	0.829	44.6	48.3	3.2	3.9
C2	20-30	Cassava	5.01	0.397	0.619	0.196	0.023	0.004	0.452	1.293	1.373	1.216	0.796	36.9	46.1	5.3	11.7
C2	50-70	Cassava	5.02	0.204	0.498	0.179	0.014	0.003	0.574	1.268	1.201	1.124	0.546	30.2	49.1	5.2	15.5
C3	0-10	Forest	5.08	0.651	0.591	0.366	0.045	0.004	0.316	1.322	1.643	1.418	1.066	42.5	47.0	5.4	5.1
C3	20-30	Forest	4.98	0.285	0.085	0.146	0.024	0.003	1.043	1.302	1.187	1.059	0.659	40.4	47.4	5.3	6.8
C3	50-70	Forest	4.94	0.162	0.095	0.132	0.012	0.003	1.081	1.323	1.309	1.229	0.470	37.5	47.3	5.7	9.6
C3	0-10	Cassava	5.25	0.284	0.303	0.108	0.031	0.003	0.291	0.736	0.731	0.692	0.585	47.4	43.2	3.1	6.3
C3	20-30	Cassava	4.96	0.228	0.205	0.065	0.016	0.004	0.861	1.151	1.054	0.956	0.549	50.6	38.3	4.4	6.7
C3	50-70	Cassava	5.09	0.087	0.193	0.041	0.009	0.006	0.741	0.992	0.774	0.758	0.345	46.2	43.6	4.3	5.8

Table 3. Selected chemical and physical properties of composite samples collected from selected depth intervals from paired sites in Northeast Thailand that are currently under a rice cropping system.

Site No.	Depth	Vegetation	$pH_{0.002}$	OC	Ca^{2+}	Mg^{2+}	$K^{=}$	Na^{+}	Exch. acidity	ECEC	$CEC_{B5.5}$	CEC_{T}	pHBC	C sand	F Sand	Silt	Clay
	(cm)			(%)	($cmol_c$/kg)								($cmol_c$/ kg.pH)	(%)			
R3	0-10	Forest	4.72	0.963	0.246	0.192	0.092	0.019	0.873	1.421	1.674	1.309	1.321	42.9	43.2	8.4	5.4
R3	20-30	Forest	4.89	0.346	0.056	0.081	0.032	0.011	0.695	0.875	1.035	0.826	0.683	44.7	43.3	8.1	3.8
R3	50-70	Forest	5.21	0.133	0.040	0.046	0.014	0.008	0.434	0.541	1.054	0.535	0.324	44.2	44.5	7.7	3.5
R3	0-10	Rice	5.09	0.668	0.601	0.110	0.040	0.036	0.212	1.000	1.210	1.072	0.759	52.2	37.7	6.7	3.5
R3	20-30	Rice	5.12	0.156	0.184	0.085	0.028	0.017	0.525	0.839	0.809	0.795	0.387	48.5	37.6	8.8	5.1
R3	50-70	Rice	4.95	0.103	0.319	0.120	0.044	0.016	0.897	1.395	1.070	1.028	0.342	45.2	40.6	7.7	6.6
R4	0-10	Forest	4.87	0.850	0.340	0.204	0.074	0.029	0.575	1.222	1.335	1.083	1.070	38.4	50.7	6.0	4.9
R4	20-30	Forest	4.91	0.337	0.041	0.051	0.030	0.020	0.539	0.681	0.743	0.640	0.552	38.7	52.1	5.4	3.8
R4	50-70	Forest	5.22	0.108	0.021	0.012	0.007	0.009	0.290	0.339	0.375	0.309	0.288	42.5	49.7	5.4	2.5
R4	0-10	Rice	5.18	0.214	0.142	0.027	0.040	0.011	0.190	0.410	0.481	0.455	0.407	42.1	49.5	5.7	2.7
R4	20-30	Rice	5.16	0.114	0.081	0.024	0.005	0.009	0.320	0.439	0.445	0.434	0.335	38.6	51.9	6.3	3.2
R4	50-70	Rice	5.39	0.042	0.021	0.007	0.003	0.007	0.208	0.247	0.361	0.384	0.218	43.0	48.1	6.2	2.8
R5	0-10	Forest	5.16	1.064	1.438	0.452	0.056	0.017	0.144	2.107	2.524	2.313	1.228	44.7	43.8	6.9	4.6
R5	20-30	Forest	5.10	0.178	0.154	0.094	0.014	0.009	0.224	0.494	0.618	0.532	0.393	43.9	47.2	5.7	3.1
R5	50-70	Forest	5.46	0.099	0.063	0.032	0.007	0.011	0.125	0.239	0.314	0.339	0.205	45.0	45.6	7.0	2.4
R5	0-10	Rice	5.03	0.286	0.161	0.045	0.017	0.022	0.863	1.108	0.672	0.626	0.446	48.2	41.6	6.3	3.9
R5	20-30	Rice	5.21	0.094	0.105	0.027	0.006	0.004	0.331	0.472	0.473	0.478	0.242	38.2	45.6	9.8	6.3
R5	50-70	Rice	4.93	0.091	0.717	0.269	0.023	0.041	0.681	1.734	1.718	1.674	0.288	31.6	44.7	12.1	11.6

A potential measure of the degree of chemical degradation that a soil has undergone due to changed management is quantification of acidification through the percent acid saturation of the cation exchange capacity. A limitation to this method lies in the assumption that the cation exchange capacity is a fixed quantity, and that degradation is associated with increasing occupation of it by Al^{3+}, to the exclusion of important nutrients (basic) cations (Noble *et al*., 2000). In fact, however, the charge fingerprint demonstrates that CEC itself, particularly the agronomically important CEC_B, decreases with pH. Hence the saturation index (S_u) was proposed by Noble *et al.* (2000) to take into account the effect of changed land use on the intrinsic surface charge characteristics of a soil. The S_u values were calculated for the 0-10 cm depth interval using Eqtn. 1 and are presented in Table 4. In this respect the S_u index ranged from 53-90% when compared to the *Dipterocarp* benchmark (Table 4). This degree of degradation is considerable and clearly shows the vulnerable nature of these soils to damage associated with changed land use.

pHBC and net acid addition rate

Associated with changes in soil organic matter, the pHBC declined with declining OC (Table 2 and 3). pHBC ranged from 1.321 to 0.205 cmol H^+/kg.unit pH over the depth intervals studied clearly demonstrating the lack of internal resistance of these soils to acid inputs. As these soils exhibited a uniform texture and were dominated by kaolinite, a generalized linear model incorporating all depth intervals as has previously been described by Aitken *et al*. (1990) was used to develop a pedotransfer function. A highly significant linear relationship between pHBC, and the attributes soil organic carbon and clay content was observed:

$$\text{pHBC} = 0.184(\pm 0.037) + 1.004(\pm 0.05)\text{OC}(\%) + 0.009(\pm 0.004)\text{Clay}(\%);\ r^2 = 0.916 \qquad (4)$$

A comparison of the measured and predicted pHBC using equation 4 is presented in Figure 4. It is of note that the slope of the line is 0.92, which is not markedly different from 1.

By substituting the pHBC values into equation (1) and knowing the number of years since conversion to agriculture, an estimation of the Net Acid Addition Rate (NAAR) was obtained (Table 4). NAAR ranged from 0.68 to 1.96 kmol H^+/ha.yr for the different production systems with the cassava systems having a lower mean rate of acid addition when compared to the rice (1.05 versus 1.50 kmol H^+/ha.yr respectively). These are relatively low rates of acid addition compared to other cropping systems in the tropics (Moody and Aitken, 1997). This may in part be attributed relatively low net proton accumulation associated with crop removal and the limited use of nitrogenous fertilizer in these production systems.

Acidity risk map

In an effort to assess the risk of accelerated acidification associated with the production of cassava and rice in Northeast Thailand, a risk map based on the soil resources database of the Department of Land Development was developed. For each soils profile, the pHBC was estimated using equation 4 for the 0-20 cm depth and a mean value calculated for each of the soil series for Northeast Thailand. By using the estimated pHBC for each of the soil series and AAR calculated for rice and cassava production systems, acidity risks maps for each of the production systems were produce depicting the number of years for the soil pH to drop to a critical water pH of 5.0 from its current value using Eqtn. 3 (Figure 5 and 6). Of the total area in Northeast Thailand 40.9 and 45.9 % were classified as lowlands and uplands, suited to the production rice and cassava respectively (Figures 5 and 6). In the case of the upland cassava production systems, 13.2 and 35.3% of the soils were classified as falling into the categories 10.1 – 20.0 and > 30 years respectively, before the soil pH falls to pH 5.0 (Figure 5). The majority (50.1%) of the soils fell into the category of 20.1 – 30 years. Contrasting this, the lowland rice cropping systems, 66.9 and 16.9% of the soils fall into the categories 10.1 – 20.0 and > 30 years respectively, before the soil pH falls to pH 5.0 (Figure 6). It should be borne in mind that the absolute values that are presented in the maps should be treated with caution since we have assumed a constant rate of acid addition and have not taken into account management factors that may influence the rate of acidification. In addition, the soil profiles that form the basis of the database have been collected during the period 1966-1988 and therefore may have undergone considerable change in chemical attributes with time (Aimsamut and Boonsompobpun, 1999).

Discussion and conclusions

During the period 1982 to 1998, 500,000 ha of climax *Dipterocarp* forest was cleared for agricultural activities, this largely being driven by a population increase in the region of 4.8 million (Office of Agricultural Economic, 2001). The impact of changed land use has resulted in a dramatic decline in the nutrient status of these soils which has been large due to declining soil OC in the region of the profile where the greatest degree of mixing occurs. Moreover, this study clearly demonstrated the fragility of these soils when cleared of their native *Dipterocarp* climax communities for agricultural production and supports the preliminary findings discussed for this region by Noble *et al*., (2000). Soils of the region are characteristically light textured sands dominated by low activity kaolinitic clays. With the decline in soil organic matter there has been a concomitant reduction in the CEC and pHBC of these soils thereby reducing the nutrient holding and water supplying capacity of these soils as well as their ability to buffer the effects of acid additions. This has had a significant impact on the productive capacity of these soils and introduces a high degree of risk.

Quantification of the degree of degradation associated with charge diminution is eloquently provided through the calculation of the saturation index (S_u). This index provides an unambiguous assessment of the extent of the problem by using a benchmark 'undisturbed' *Dipterocarp* forest as reference. From a management perspective the index allows both a an assessment of the extent of the problem as well as the degree of remediation that is required to bring the charge characteristics back to their original undisturbed state. As clearly indicated the driver of this charge diminution is the loss of organic carbon due to continuous tillage. The restoration of soil organic matter status would significantly reduce the aforementioned decline in CEC and cation loss due to changed land use. However, this is not easily achievable in tropical and sub-tropical environments where regular cultivation is undertaken in the preparation of seedbeds and weed control. The introduction of long-term grass leys in rotation with crops would increase the soil organic carbon content and have a direct benefit on the charge characteristics of the soil (Noble *et al*., 1998). However, to resource poor farmers in developing countries whose primary objective is house-hold food security, the implementation of long-term grass leys into their farming systems is often viewed as an unattractive option. In addition, *in situ* generation of organic matter on these degraded soils may not be possible without large inputs of inorganic fertilizers and water.

There is mounting empirical evidence to suggest that 'conservation agriculture' systems are an effective alternative to conventional farming (tillage based) systems that effectively exploit the natural resources upon which they are based without degrading them, and in some cases allowing their restoration (Bot and Benites, 2001). The two essential features of 'conservation agriculture' are no-tillage and the maintenance of a cover on the soil surface. Significant increases in productivity have been achieved through the adoption of 'conservation agriculture' (Bot and Benites, 2001). However, these responses are contingent on the inherent fertility status of the soil. Furthermore, on highly degraded production systems, the positive productivity benefits associated with the adoption of organic matter conservation systems may have a lag phase associated with a build up of OC to some critical level. This may influence adoption of such practices under particular socio-economic circumstances.

The use of high-activity clays and Ca-silicated slags, materials that are commonly found throughout the world and are currently being evaluated in Thailand and Australia, may be a plausible management strategy to permanently increase the surface charge characteristics of degraded soils (Noble *et al*., 2001, 2003). Relatively modest rates of application have been shown to result in a significant enhancement in productivity over a prolonged period. The advantage of undertaking such a strategy is that it may be termed a 'one-off' investment that would only require the 'topping up' of basic cations on a needs basis (Noble *et al*., 2003).

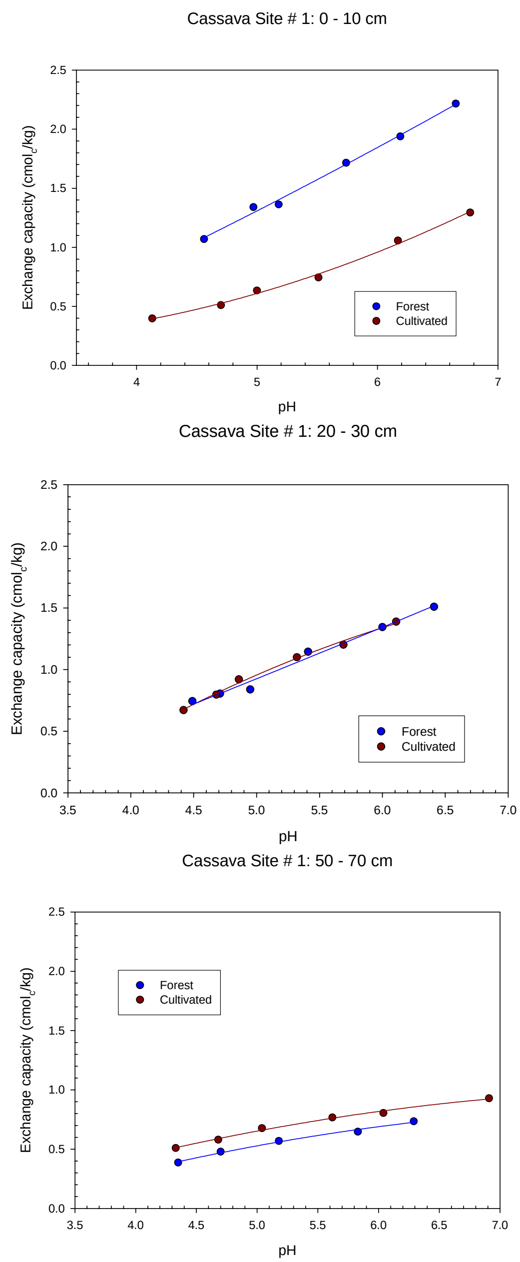

Figure 1. Surface charge fingerprints (CEC_b) of cultivated and adjacent forest sites C1 for the (a) 0-10 cm; (b) 20-30 cm; and (c) 50-70 cm respectively.

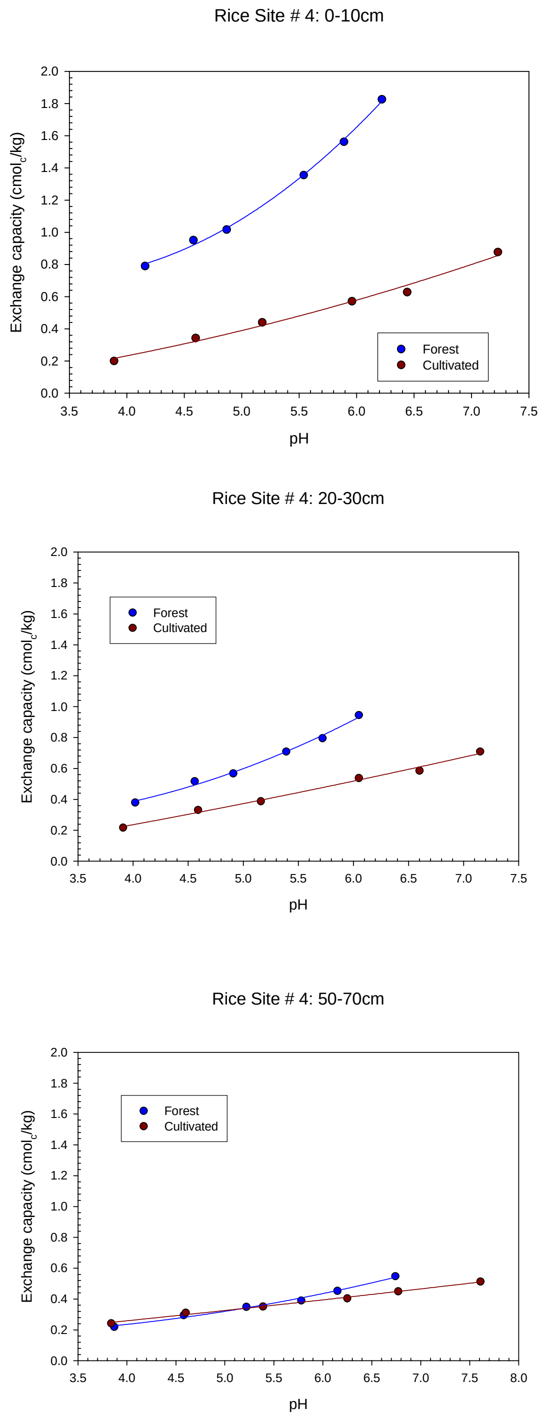

Figure 2. Surface charge fingerprints (CEC_b) of cultivated and adjacent forest sites R4 for the (a) 0-10 cm; (b) 20-30 cm; and (c) 50-70 cm respectively.

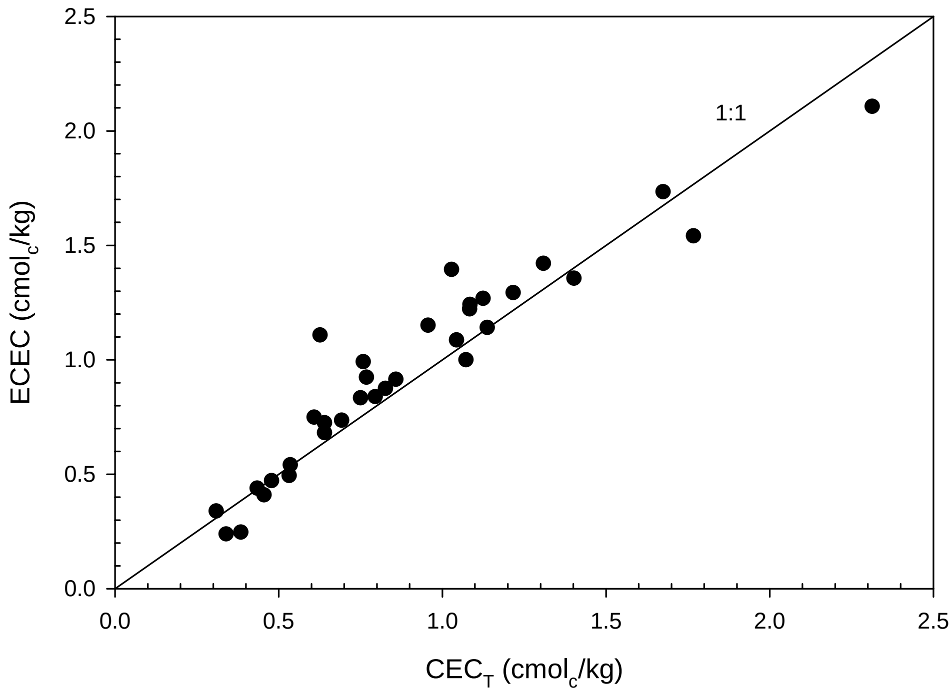

Figure 3. Relationship between the effective cation exchange capacity (ECEC) and the total cation exchange capacity (CEC_T) over all depth intervals.

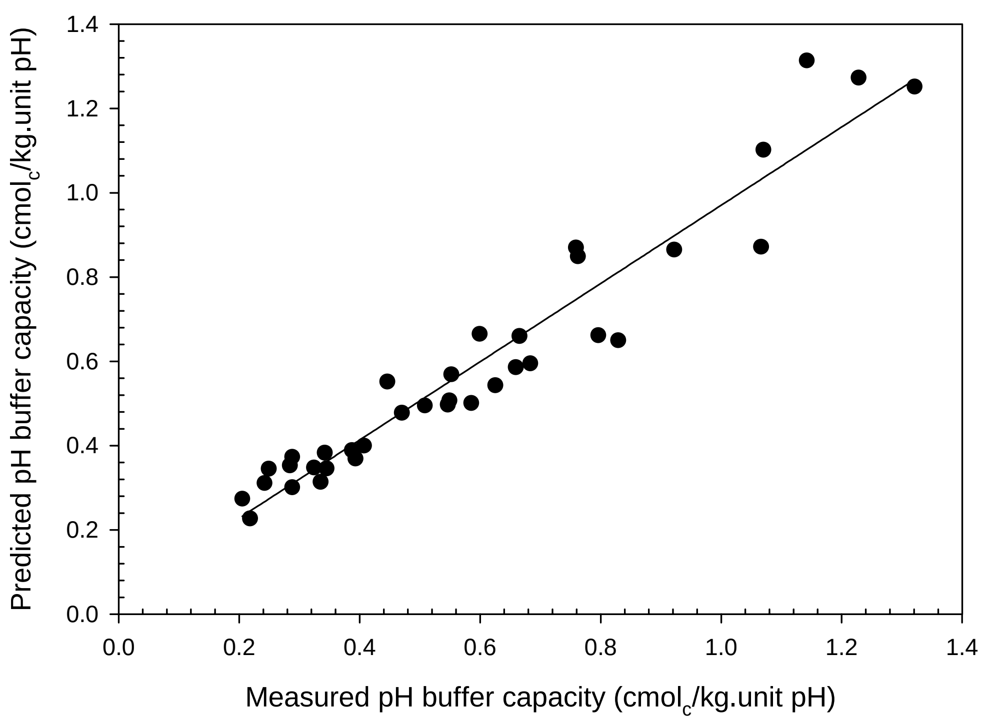

Figure 4. Relationship between measured and predicted pHBC using soil organic carbon and clay content from Northeast Thailand. Equation for the curve is $y = 0.042 + 0.928x$; $r^2 = 0.928$.

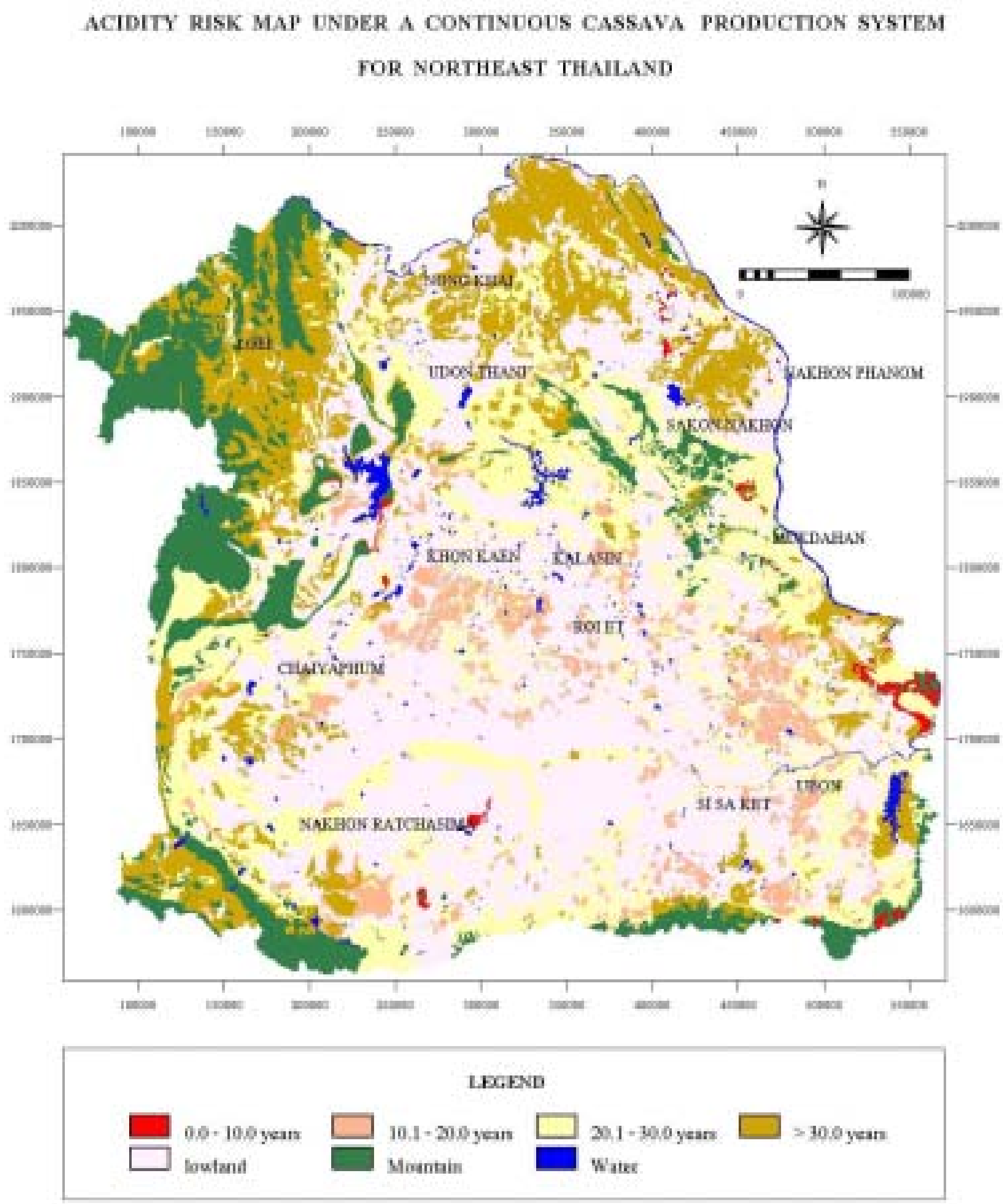

Figure 5. Acidification risk map for cassava production systems for upland regions of Northeast Thailand based on the time required for the soil pH to decline from its current value to 5.0.

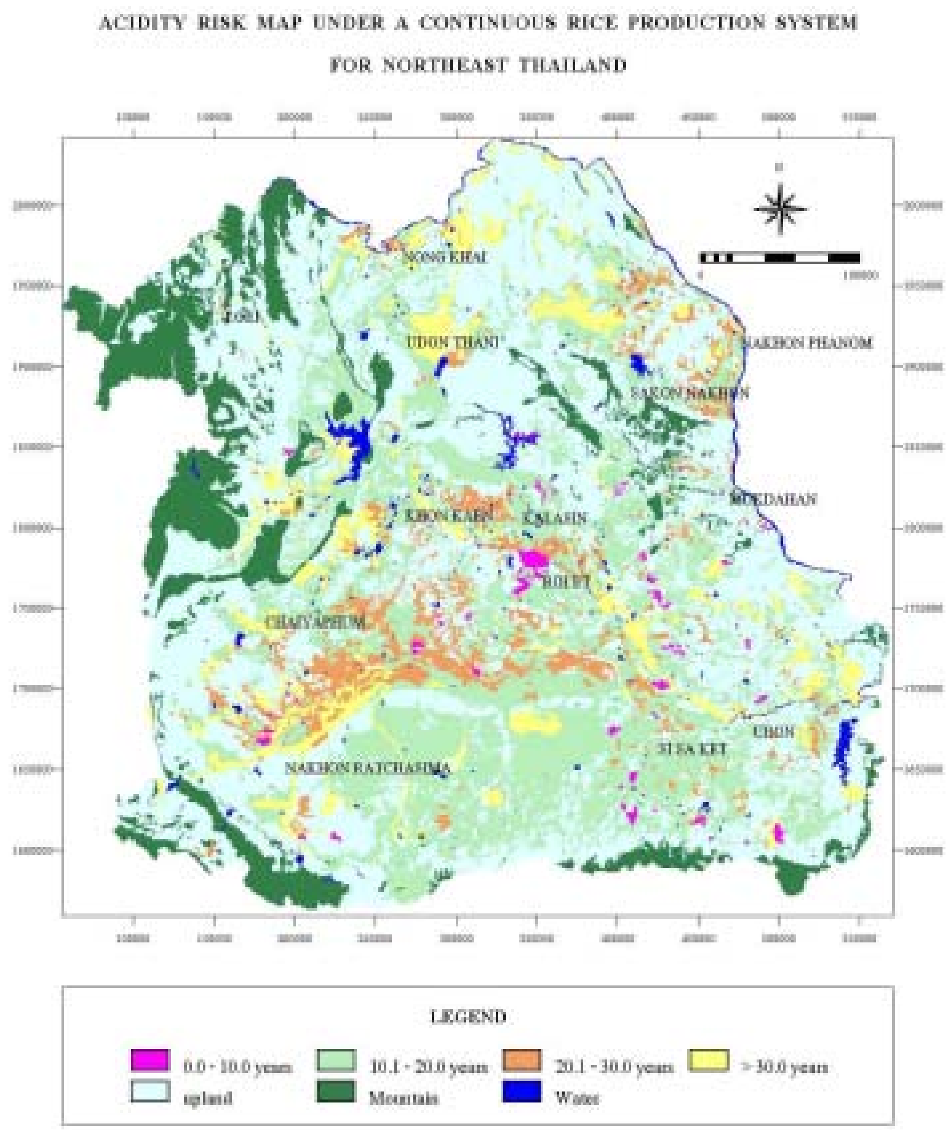

Figure 6. Acidification risk map for continuous rice production systems for lowland regions of Northeast Thailand based on the time required for the soil pH to decline from its current value to 5.0.

The graphical representation of risk, as measured in years, associated with the production of the two dominant crops (cassava and rice) in region, reinforces the fragility of these soils. Relatively low inputs of acidity associated with these cropping systems, will in a relatively short period, result in soil pH values dropping to a critical level that would significant impact on yield and the range of crop species potentially grown. This will have a significant impact on food security and the poverty profile for the region.

For the suite of soils that are typical of Northeast Thailand, the development of a pedotransfer function based on routinely measured soil attributes of soil organic carbon and clay will assist extension personnel and resource managers in assessing the risk of accelerated acidification associated with different cropping systems. For example, by differentiating soils that are predisposed to accelerated acidification, resource manager may strategically recommend the establishment of crops that have a low net acid addition rate or implement management strategies that minimize the risk of accelerated acidification i.e. prophylactic applications of lime.

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